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Dispersion induced penalty for 1xN passive interferometric optical MUX/DEMUXs and its reduction using all-pass filters

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Abstract *The cascadability of 1xN passband flattened interferometer DEMUX is investigated numerically. The passband flattening process results in detrimental dispersion induced penalty at 10 Gbit/s which can be significantly reduced with all-pass filters on the input arm.*

Introduction

1xN optical multi and demultiplexers (MUX/ DEMUX) are used in wavelength division multiplexed networks to combine/ separate either individual channels or a number of these collectively. For large N, passive optical MUX/ DEMUX are conventionally fabricated as arrayed waveguide gratings, while for small N there are several possible implementations, as grating [1], thin film [2] or interferometer based components [3]. In this paper, interferometer based components are considered, where the restriction to low N stems from the difficulty of making uniform, loss less NxN couplers for large N. For simplicity the discussion is restricted to a 1x4 DEMUX with a free spectral range (FSR) of 100 GHz, corresponding to 25 GHz channel spacing. Fig. 1 shows a schematic of the DEMUX. It consists of a uniform 1x4 coupler, 4 interferometer arms with discrete arm lengths difference (leading to delays differing by units of ΔT) and a uniform 4x4 coupler. Each interferometer arm contains a phase controlling element (α_q) and a single-stage all-pass filter (a ring resonator) with a FSR equal to the channel spacing.

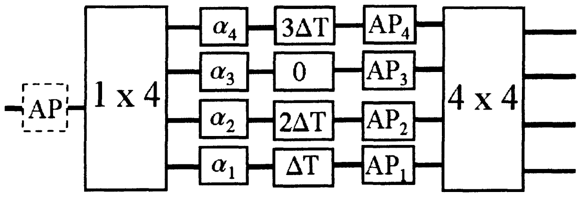

Fig. 1: An interferometer based 1x4 DEMUX, *where* α_q *denote the phase controllers,* ΔT *the delays and* AP *the all-pass filters. The dotted box on the input arm shows the additional all-pass filter used for dispersion compensation.*

Inherently the spectral response of a 1xN interferometer has large crosstalk between adjacent bands and lacks passband flatness [3], but the transmission can be flattened by adding a single-stage all-pass filter in each interferometer arm, where the filters are off-resonance at the centre of the passband and have pole magnitudes that decrease with the interferometer arm length [4]. The phase response of an all-pass filter with large pole magnitude changes rapidly close to its resonance frequency. Thus the all-pass filters add a significant cubic dispersion to the complex transfer function of the DEMUX. For an optimised 1x4 DEMUX with a FSR of 100 GHZ the average dispersion slope over a 60% passband is $-8 \cdot 10^3$ ps/nm^2 [5]. In comparison a dispersion slope of $34 \cdot 10^3$ ps/nm^2 has been reported to give a power penalty on the order of 2 dB [6]. By adding a three-stage all-pass filter on the DEMUX's input arm, the maximum dispersion of all channels over the passband can be reduced by a factor of 16, without changing the amplitude transfer [5]. In this paper, numerical simulations are used to assess the detrimental effect of the DEMUX's dispersion on its cascadability for a 10 Gbit/s implementation. We show that for a cascade of 10 DEMUXs the amplitude transfer function induces negligible penalty for a detuning of ±5 GHz, whereas the dispersion gives a 1.6 dB penalty even at zero detuning. Adding a dispersion compensating all-pass filter results in less than 0.4 dB penalty for a cascade of 10 components and a detuning of ±2 GHz, a significant improvement.

Simulation

The following settings are used for the numerical simulations. A continuous wave laser (0 dBm average power and negligible line width) is externally modulated with a 1024 bit nonreturn-to-zero 10 Gbit/s pseudo-random sequence in a chirp free Mach-Zehnder modulator with an extinction ratio of 30 dB. The modulated signal is sent through a cascade of DEMUXs (which are assumed to be identical and with the same detuning with respect to the laser frequency) and is subsequently detected in a PIN photodiode (responsivity of 1.2 A/W and thermal noise single-sided density of 15 pA/Hz$^{0.5}$) followed by a fourth order low-pass Bessel electrical filter with a bandwidth of 7.5 GHz. These settings give a back-to-back sensitivity of -21.7 dBm at a bit-error-rate of 10^{-9}. The power penalty is found from a Gaussian bit-error-rate evaluation taking intersymbol interference between three consecutive bits into account [7].

Results

Fig. 1 shows the simulated power penalty arising from the amplitude transfer function (assuming no dispersion) after 1 and a cascade of 4, 7 and 10 DEMUXs. The amplitude transfer function of the DEMUX is also shown. It has transmission uniformity of better than 0.1 dB for a detuning of up to ±10 GHz and a 3 dB bandwidth of 24.7 GHz. The figure shows that the amplitude transfer gives negligible power penalty for a cascade of up to 10 DEMUXs and a detuning of less than ±5 GHz. This behaviour is due to the uniformity in the passband and steep slopes of the amplitude transfer function, resulting in minor bandwidth narrowing when the device is cascaded.

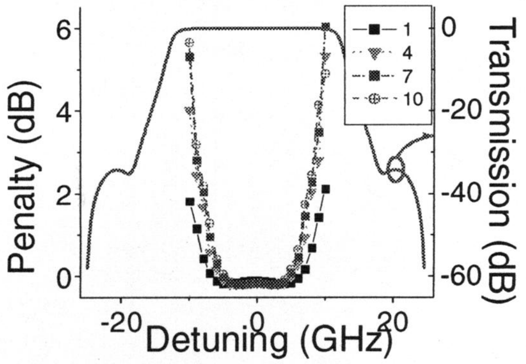

Fig. 2: Simulated penalty from the amplitude transfer of the DEMUX as a function of the detuning. Data are shown for 1 and a cascade of 4, 7 and 10 DEMUX's.

Fig. 2 shows the calculated dispersion and the dispersion induced penalty of the DEMUX (where the amplitude transfer function is assumed to be uniform over the entire frequency range). For zero detuning the penalty remains low up to a cascade of 4, but increases to ~1.6 dB for 10 DEMUXs. Furthermore, the tolerable detuning for a fixed penalty is reduced when the number of cascaded devices is increased, resulting in tight requirements for the transmitter frequency if such DEMUXs are to be used in practice.

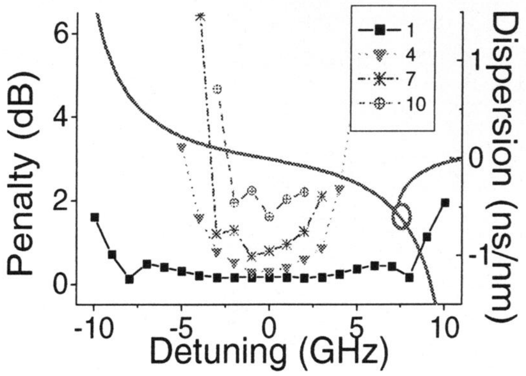

Fig. 3: Simulated dispersion induced penalty and calculated dispersion of the DEMUX as a function of the detuning.

Adding a three-stage all-pass filter on the input arm can reduce the dispersion of the device. Fig. 4 shows the corresponding calculated dispersion and simulated dispersion induced penalty for the compensated DEMUX. The penalty for zero detuning remains below 0.4 dB when the number of cascaded DEMUXs is increased up to 10, and a larger tolerance to laser misalignment is observed when compared to Fig. 3. For a power penalty of 0.4 dB the tolerable detuning is ±3 GHz and ±2 GHz for a cascade of 7 and 10 DEMUX's, respectively.

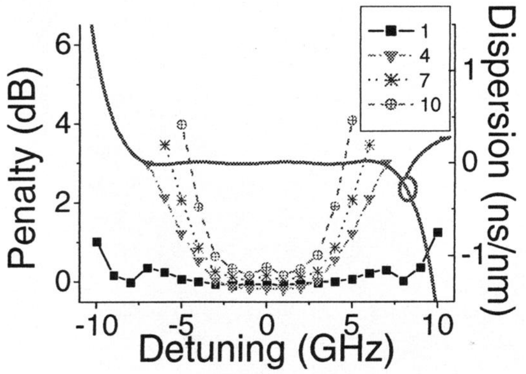

Fig. 4: Simulated dispersion induced penalty and calculated dispersion of the DEMUX with a dispersion compensating filter as a function of the detuning.

Conclusion

The cascadability of 1xN interferometer DEMUXs designed for 100 GHz channel spacing at 10 Gbit/s has been investigated numerically. It has been shown that flattening the passband and reducing the crosstalk level by inserting all-pass filters in each of the interferometer arms would result in negligible penalty over a bandwidth of up to 10 GHz after 10 cascaded devices, if it were not for the significant cubic dispersion. Adding a three-stage all-pass filter on the input arm has been suggested as a way to reduce the dispersion, thus reducing the power penalty from 1.6 dB at zero detuning to less than 0.4 dB over a detuning of up to ±2 GHz. This demonstrates the effectiveness of the proposed dispersion compensation stage in the DEMUX design.

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